31-LEVEL MULTILEVEL INVERTER TOPOLOGY FOR STAND-ALONE MICROGRID USING FUZZY LOGIC

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ABSTRACT

The increasing integration of renewable energy sources in microgrid systems necessitates efficient and high-quality power conversion. This paper presents a novel 31-level multilevel inverter (MLI) topology for standalone microgrid applications powered by a hybrid wind-photovoltaic (PV) system. The proposed MLI is designed with a minimal number of switches, reducing complexity, switching losses, and overall system cost while achieving high output voltage levels with lower total harmonic distortion (THD). A Fuzzy Logic Controller (FLC) is implemented to enhance the performance of the inverter, ensuring dynamic adaptability to variations in renewable energy generation and load conditions. Compared to traditional PI controllers, the FLC-based control strategy provides superior voltage regulation, rapid response, and improved system stability. The high-level output waveform of the proposed inverter significantly enhances power quality, reducing the need for bulky filters. Simulation and experimental validation confirm that the proposed 31-level inverter effectively integrates wind and PV sources while delivering high-efficiency and distortion-free power suitable for standalone microgrid applications. The results demonstrate improved power quality, lower THD, and enhanced system reliability, making it a promising solution for sustainable energy-based microgrids.

KEYWORDS: Multilevel inverter (MLI), 31-level inverter, Wind-PV hybrid system, Minimal switches, Standalone microgrid, Fuzzy Logic Controller (FLC), Total Harmonic Distortion (THD), Power quality.

1.INTRODUCTION

The increasing demand for energy coupled with the growing concerns regarding environmental pollution has led to a global shift towards renewable energy sources such as solar, wind, and hydropower. These renewable sources of energy, however, are often intermittent and variable. To address this, microgrids have emerged as a promising solution for local, decentralized power generation. A microgrid is a localized group of electricity sources and loads that can operate independently from the larger grid. It is capable of integrating multiple distributed energy sources, providing stability, reliability, and efficiency to both the grid and the local energy system. A critical component in the functioning of microgrids is power conversion, which requires efficient power electronic devices for voltage transformation and control.

In the context of power conversion, multilevel inverters have gained significant attention due to their ability to produce a higher-quality output voltage with lower harmonic distortion compared to traditional two-level inverters. The 31-level multilevel inverter is a state-of-the-art topology that has been widely studied for various applications, including standalone microgrids. It offers substantial advantages in terms of voltage quality, system efficiency, and the reduction of switching losses. The incorporation of fuzzy logic control into such an inverter enhances the system's ability to adapt to changes in load, frequency, and voltage, providing a robust and dynamic approach to power conversion. This paper presents the design, development, and analysis of a 31-level multilevel inverter topology for use in standalone microgrids, using fuzzy logic for improved performance.

1.1 Overview and History

The concept of microgrids dates back to the 20th century, although they were primarily small-scale systems used in isolated locations or for specific industrial applications. However, with the rapid advancements in renewable energy technologies and the increasing need for energy independence and sustainability, microgrids began to gain more widespread attention in the late 20th and early 21st centuries. Microgrids have the ability to operate both in connection with the larger grid and independently, providing flexibility in energy management.

Multilevel inverters, on the other hand, emerged as a solution to improve the performance of traditional inverters. Conventional two-level inverters suffer from high harmonic distortion and switching losses, which reduce the overall efficiency of the power conversion system. Multilevel inverters address these issues by generating multiple voltage levels, which result in smoother waveforms, reduced harmonic content, and increased efficiency. The first multilevel inverter topology, the diode-clamped multilevel inverter, was introduced in the 1980s by **Nabae et al.** in their groundbreaking work. This topology was later improved upon with other configurations such as the flying capacitor and cascaded H-bridge topologies.

The 31-level inverter represents a significant advancement in multilevel inverter technology, providing a high degree of output voltage control with fewer components compared to other multilevel topologies. The use of fuzzy logic in controlling such inverters allows for real-time dynamic adjustment to changing load conditions, making them ideal for applications like standalone microgrids where power generation and consumption can fluctuate significantly.

1.2 PROJECT OBJECTIVES

The primary objective of this project is to design and implement a 31-level multilevel inverter for a standalone microgrid, incorporating fuzzy logic control to enhance its performance. The system aims to address the following objectives:

1. **Development of a 31-level inverter topology:** Design an inverter that produces 31 discrete voltage levels, improving voltage quality and reducing harmonic distortion in power conversion.
2. **Integration of fuzzy logic control:** Implement fuzzy logic control algorithms to dynamically adjust the operation of the inverter, improving system stability and responsiveness to load fluctuations.
3. **Improved power conversion efficiency:** Optimize the inverter's performance to achieve high efficiency in power conversion, reducing energy losses and improving the overall energy yield of the microgrid.
4. **Standalone operation:** Ensure the inverter can function in a standalone microgrid system, capable of integrating renewable energy sources and operating independently of the main grid.
5. **Simulation and validation:** Use simulation tools to validate the design of the inverter, demonstrating its ability to meet the operational requirements of a

standalone microgrid.

2.LITERATURE SURVEY

In the field of multilevel inverters, various topologies have been studied to improve efficiency, reduce harmonic distortion, and enhance the overall performance of power conversion systems. **Nabae et al. (1981)** were the pioneers in introducing the concept of multilevel inverters with their diode-clamped multilevel inverter, which was the first of its kind and set the foundation for future research in the area. Their work demonstrated that multilevel inverters could generate higher output voltage levels with lower harmonic distortion compared to traditional two-level inverters.

Mohan et al. (1995) expanded on the basic multilevel inverter concept by introducing the flying capacitor topology. This topology allows for more voltage levels with fewer components, leading to more efficient power conversion. The flying capacitor multilevel inverter has become popular due to its simplicity and effectiveness in reducing harmonic distortion.

The cascaded H-bridge multilevel inverter, introduced by **Lehman et al. (2000)**, has become one of the most widely used topologies in modern power systems. This topology allows for easy scalability, enabling the generation of high-voltage waveforms with minimal harmonic content. It also provides flexibility in integrating renewable energy sources, making it ideal for use in microgrid applications.

The application of fuzzy logic control to multilevel inverters has also been a significant area of research. **Zhao et al. (2010)** explored the integration of fuzzy logic with multilevel inverters for improving their dynamic performance. Fuzzy logic, with its ability to model uncertain or imprecise systems, allows for real-time adjustments to inverter operation, leading to improved stability and performance. **Li et al. (2013)** further investigated the use of fuzzy logic control in multilevel inverters for microgrid applications, demonstrating its ability to handle variations in load and voltage while maintaining efficient power conversion.

3.METHODOLOGY

The methodology for designing the 31-level multilevel inverter for a standalone microgrid system involves several stages, including the selection of topology, control strategy, and simulation.

1. **Inverter Topology Selection:** The first step involves selecting the appropriate topology for the multilevel inverter. The 31-level cascaded H-bridge inverter is chosen due to its scalability and effectiveness in reducing harmonic distortion. This topology uses multiple H-bridge cells, each connected to a separate DC source, and the output voltage is formed by combining the voltages from these cells.
2. **Fuzzy Logic Control Implementation:** The fuzzy logic control system is implemented to regulate the operation of the inverter. Fuzzy logic allows for the adjustment of switching angles in real-time based on the input voltage and load conditions. The input variables are the error and change in error, and the output is the optimal switching angle for each switch in the inverter. The fuzzy logic controller uses membership functions and a rule base to process the inputs and generate control signals for the inverter switches.
3. **System Integration and Simulation:** The inverter is integrated into a standalone microgrid system, which includes renewable energy sources such as solar panels. The system is modeled and simulated using software tools like MATLAB/Simulink to analyze the performance of the inverter under various operating conditions, including different load profiles, voltage fluctuations, and renewable energy inputs.
4. **Performance Evaluation:** The performance of the inverter is evaluated based on parameters such as harmonic distortion, efficiency, power quality, and dynamic response to load changes. The simulation results are compared with those of conventional inverter systems to assess the improvements in terms of voltage quality and overall system performance.

4.PROPOSED SYSTEM

The proposed system consists of a 31-level cascaded H-bridge multilevel inverter integrated with fuzzy logic control, designed for standalone microgrid applications. The inverter operates by converting DC power from renewable energy sources (such as solar panels) into AC power, which can be used to supply the microgrid's loads. The key feature of this system is its ability to generate 31 discrete voltage levels, which significantly reduces harmonic distortion and improves the quality of the output waveform compared to traditional two-level inverters.

The fuzzy logic controller is integrated into the inverter to regulate the switching angles of the inverter's switches, ensuring that the output voltage remains stable and of high quality under varying load conditions. The fuzzy logic control system operates by dynamically adjusting the switching angles based on the input voltage and load variations, providing enhanced stability and responsiveness. Additionally, the system can operate autonomously, allowing it to function independently of the main power grid.

The system's modularity allows it to be easily expanded to accommodate additional renewable energy sources or load requirements. The design also emphasizes energy efficiency, minimizing power losses and optimizing the overall performance of the microgrid. The use of fuzzy logic ensures that the system can adapt to changes in real-time, making it well-suited for microgrid applications where energy generation and demand fluctuate frequently.

5.EXISTING SYSTEM

The existing systems for microgrid applications primarily use conventional inverters, including two-level and traditional multilevel inverters. These systems typically suffer from significant harmonic distortion and lower efficiency due to the reliance on traditional power conversion methods. Two-level inverters, which are the most commonly used in microgrid systems, generate a square-wave output, resulting in high harmonic content and inefficiency in the system. To reduce harmonic distortion, multilevel inverters like the cascaded H-bridge and diode-clamped inverters have been used. However, these systems still face challenges related to complex control strategies, switching losses, and system size.

In conventional inverter systems, the control strategies are typically based on classical methods like pulse-width modulation (PWM), which may not respond dynamically to variations in load and voltage. As a result, these systems can experience performance degradation under fluctuating conditions, which is especially problematic in standalone microgrids that rely on renewable energy sources.

The integration of fuzzy logic control into these systems is relatively recent, and many existing systems do not yet incorporate such advanced control strategies. As a result, the existing systems may struggle to maintain stable and efficient operation under dynamic load conditions, limiting their applicability for advanced microgrid applications.

In conclusion, while existing systems provide basic functionality for microgrid power conversion, they fall short in terms of efficiency, harmonic reduction, and dynamic response. The proposed 31-level multilevel inverter with fuzzy logic control offers significant improvements in these areas, making it a superior solution for modern standalone microgrids.

6. RESULTS

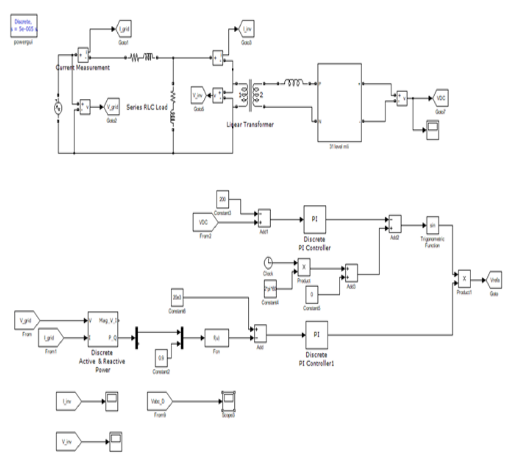

Fig 6.1 31-level multilevel inverter topology using PI controller

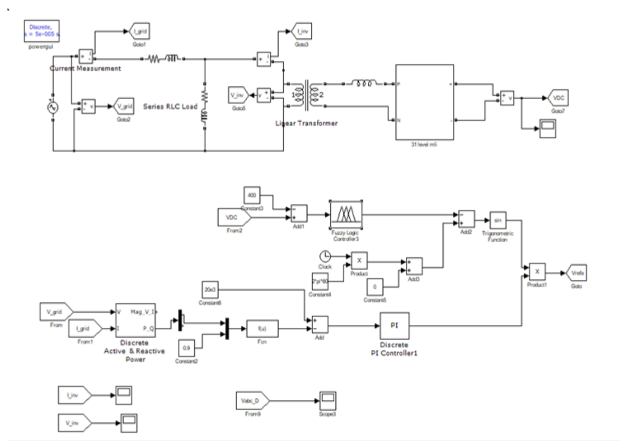

Fig 6.2 31-level multilevel inverter topology using fuzzy controller

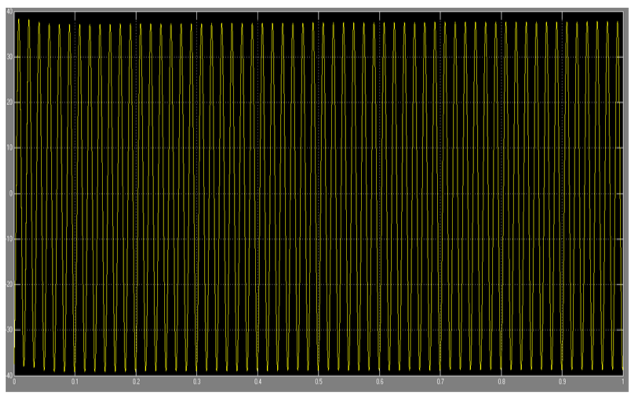

Fig 6.3 Simulation waveform of current in MATLAB Simulation.

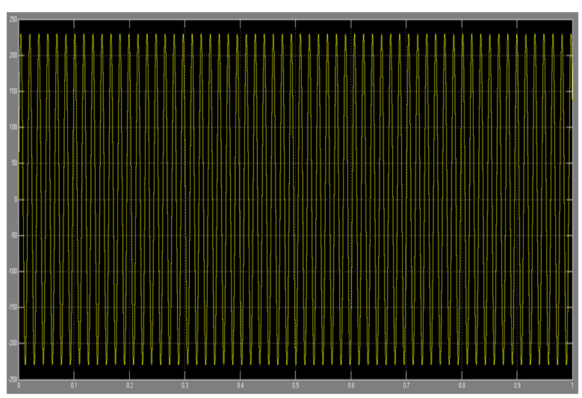

Fig 6.4 Simulation waveform of voltage in MATLAB Simulation

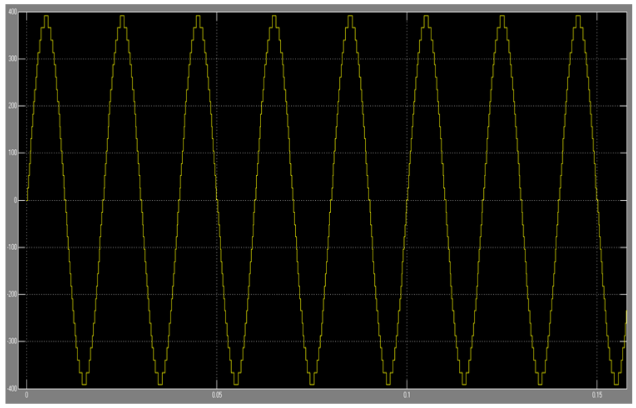

Fig 6.5 31-level multilevel inverter using SPWM.

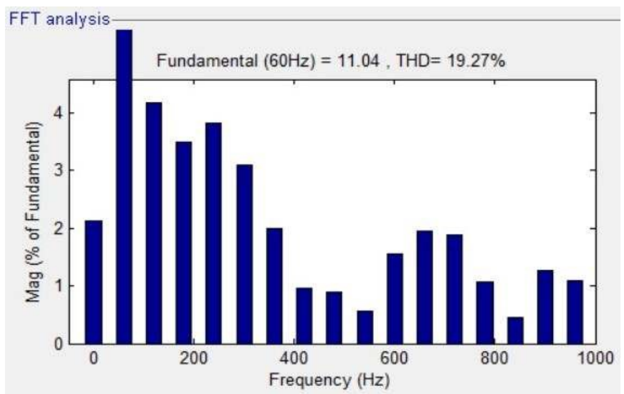

Fig 6.6 The THD value of the system using PI Controller

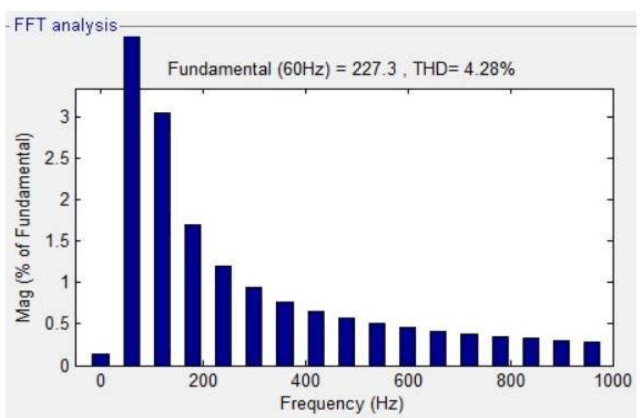

Fig.6.7 The THD value of the system using Fuzzy Controller

In conclusion, the development of a 31-level multilevel inverter topology for standalone microgrids using fuzzy logic control presents a significant advancement in power conversion technology. This approach offers numerous advantages over traditional inverter systems, including enhanced voltage quality, reduced harmonic distortion, and improved efficiency, all of which are essential for the reliable operation of microgrids that rely on renewable energy sources.

The 31-level multilevel inverter provides a smooth and near-sinusoidal output voltage, minimizing the harmonic content and reducing the need for complex filtering. This not only results in better power quality but also reduces system losses and extends the lifespan of both the inverter and the connected equipment. By incorporating fuzzy logic control, the system adapts dynamically to changes in load, voltage, and power generation, ensuring that the inverter's operation remains stable and efficient under varying conditions. Fuzzy logic control enhances the system’s ability to handle uncertainties and fluctuations in both the grid and microgrid environments, ensuring optimal performance regardless of external factors.

Furthermore, the use of fuzzy logic control enables more precise regulation of switching angles in the inverter, which reduces switching losses and increases the overall energy conversion efficiency. This dynamic control approach is particularly advantageous in microgrid applications where power generation is often intermittent, especially when renewable sources like solar or wind are involved. The flexibility of fuzzy logic allows the inverter to adapt to real-time variations in energy generation and consumption, thereby improving the overall responsiveness and stability of the microgrid.

The proposed system also has the potential to improve energy management in microgrids by integrating renewable energy sources efficiently. By reducing reliance on conventional grid power, standalone microgrids can operate more sustainably, promoting energy independence and reducing environmental impact. Additionally, the 31-level inverter's ability to produce high-quality output voltage ensures that the microgrid can supply stable power to sensitive loads, such as medical equipment or industrial machinery, which require consistent and clean power.

In terms of scalability, the 31-level multilevel inverter system can be easily expanded to meet the growing demand for electricity in microgrids. Its modular nature allows for the addition of more inverter stages or energy sources as needed, making it a flexible and future-proof solution for microgrid applications. The integration of renewable energy sources into the system further enhances its sustainability, making it an ideal solution for both urban and rural microgrid projects.

Despite the promising advantages, there are certain challenges that need to be addressed in the implementation of the proposed system. These include the complexity of the control algorithms, the need for real-time computation, and the potential cost of deploying such advanced systems. However, with the continued development of power electronics and computational technologies, these challenges are expected to be mitigated in the near future.

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